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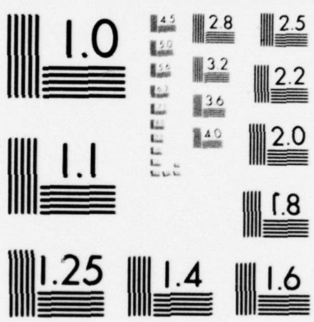
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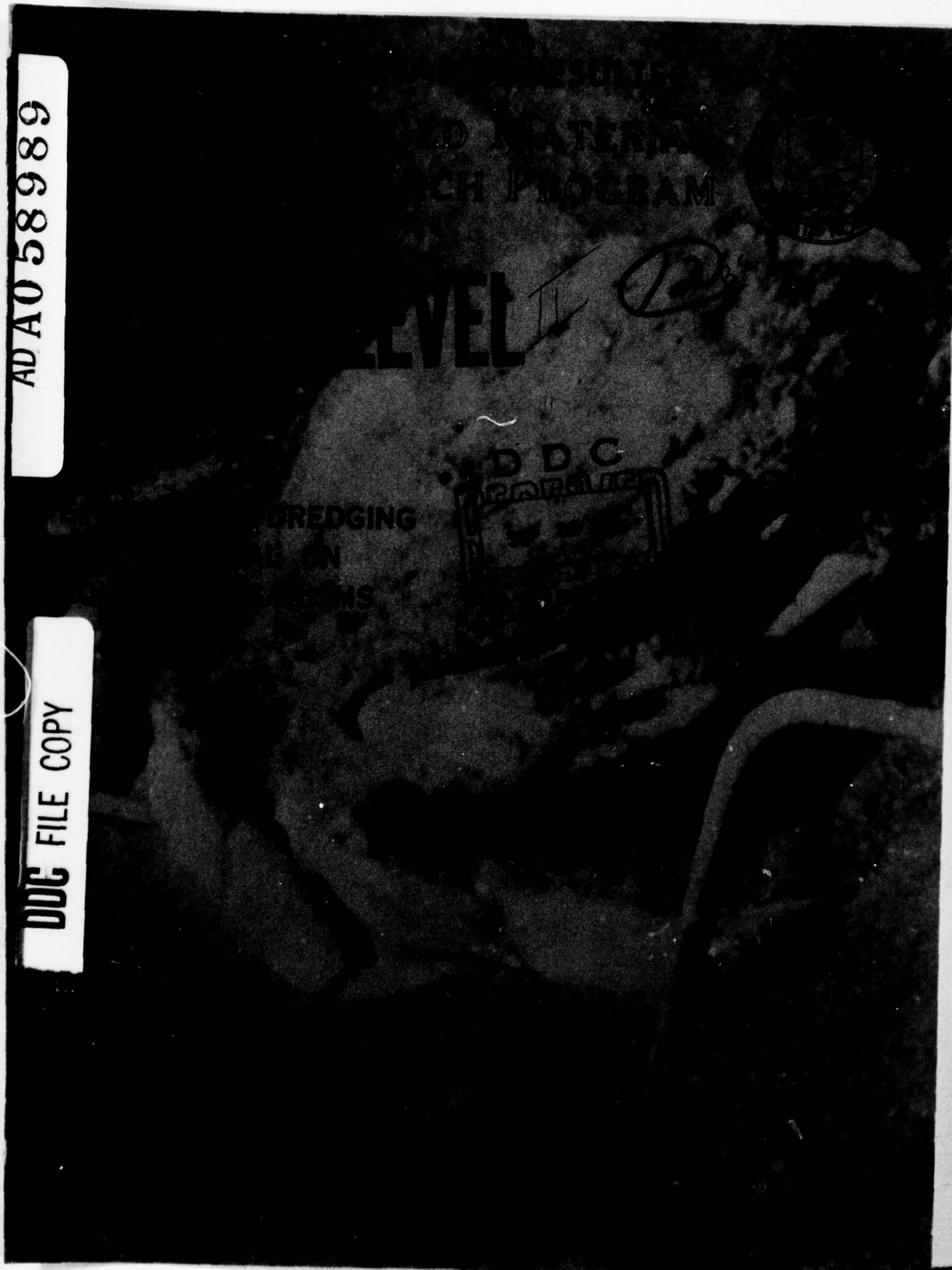
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| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>Technical Report DS-78-5 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>6 EFFECTS OF DREDGING AND DISPOSAL ON AQUATIC ORGANISMS | | 5. TYPE OF REPORT & PERIOD COVERED<br>9 Final report |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>10 Nina D. Hirsch, Louis H. DiSalvo, Richard Peddicord | | 8. CONTRACT OR GRANT NUMBER(s)<br>12 46p. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Naval Biosciences Laboratory, University of California, Naval Supply Center, Oakland, California 94625 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>DMRP Task 1D |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Office, Chief of Engineers, U. S. Army<br>Washington, D. C. 20314 | | 12. REPORT DATE<br>11 Augu[redacted]978 |
| | | 13. NUMBER OF PAGES<br>41 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)<br>U. S. Army Engineer Waterways Experiment Station<br>Environmental Laboratory<br>P. O. Box 631, Vicksburg, Miss. 39180 | | 15. SECURITY CLASS. (of this report)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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| Aquatic life | Dredging |
| Aquatic microorganisms | Environmental effects |
| Contamination | Suspended sediment |
| Dredged material | Water pollution sources |
| Dredged material disposal | |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report synthesizes data from the U. S. Army Corps of Engineers' Dredged Material Research Program, Task 1D. Task 1D consisted of six research projects (work units) that investigated the direct and indirect effects of dredging and disposal of dredged material on aquatic organisms.

Determination of potential environmental effects of dredging and disposal, in spite of research conducted to date, is still in preliminary stages due to the multiplicity of variables involved.

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20. ABSTRACT (Continued).

Direct effects of dredging and disposal are restricted to the immediate area of operation. They include removal of organisms at dredging sites and burial of organisms at disposal sites. Data indicate that the recovery of disturbed sites occurs over periods of weeks, months, or years depending on the type of environment. Possible mechanisms of recolonization include lateral and vertical migration of organisms and larval recruitment. Disturbed sites may be recolonized by opportunistic species which are not normally the dominant species occurring at nearby undisturbed sites.

Most organisms studied were relatively insensitive to the effects of sediment suspensions in the water. Dredging-induced turbidity is probably not of major environmental concern in most cases, but may be an aesthetic problem. The formation of fluid mud due to dredging and disposal is a poorly understood process and is of probable environmental concern. Available data indicate that suspensions of highly contaminated sediments have a greater potential for adverse effects than uncontaminated or lightly contaminated sediments.

CONT → Bioavailability of sediment-sorbed heavy metals is low. Release of sediment-associated heavy metals and their uptake into organism tissues have been found to be the exception rather than the rule. Research results suggest that there is little or no correlation between the bulk sediment content of heavy metals and environmental impact. Oil and grease residues, like the heavy metals, seem tightly bound to sediment particles and accumulation of these residues by organisms is minimal.

The diversity of variables that have the potential for direct and indirect effects on aquatic life argues for an integrated, whole-sediment bioassay, using sensitive test organisms. Such a procedure is currently under development by the Environmental Protection Agency and the Corps of Engineers and should uncover site-specific toxicity problems which can be addressed by appropriate chemical testing and biological evaluation of dredged material.

## SUMMARY

The Corps of Engineers' Dredged Material Research Program (DMRP) examined many aspects of dredging and disposal from an environmental viewpoint. The purpose and scope of this report are to evaluate and synthesize data from DMRP Task 1D entitled "Effects of Dredging and Disposal on Aquatic Organisms." Task 1D included six research efforts that dealt with the direct and indirect effects of dredging and disposal on aquatic organisms. The aspects of dredging and disposal investigated for potential environmental effects were the physical disruption of the bottom environment, the generation of suspended sediments, and the contaminant load of the sediments being disturbed and redistributed.

The research reviewed is in the forefront of applied environmental science and is a beginning in defining the occurrence of environmental perturbations due to dredging and disposal. Most of the studies reviewed in this synthesis report describe worst-case experimental conditions. Although limited in scope, experimental results showing lack of effects under these conditions support the conclusion that indirect (long-term and sublethal) effects of dredging and disposal will be minimal.

Potential environmental effects of dredging and disposal are not yet completely understood due to the many variables involved. Dredging and disposal operations are carried out in many geographic locations with a wide range of aquatic environments. Waters may have different salinity regimes and different levels of natural turbidity. Disturbed areas may have different contaminant burdens in the water and sediments. A major variable is the presence of organisms and the species diversity that characterize the different dredging and disposal sites. Even different methods of dredging and disposal may affect the environmental impact of a given project.

### Physical Disruption of Bottom Environment

Dredging and disposal operations have immediate localized effects on the bottom life. Direct effects of dredging include removal of the

existing natural or established community with widely varying survival of organisms during dredged material excavation. At the disposal site, organisms are buried under various depths of dredged material. Both dredging and disposal can create a new substrate that may or may not resemble the original sediments. Aside from the physically disruptive effects, the long-term environmental concern is the recovery (repopulation) of bottom areas where dredging or disposal has occurred.

Literature review and DMRP Task 1D work show that organisms in dredging areas are decimated initially, but populations recover with time. The recovery at the disturbed sites occurs over periods of weeks, months, or years, depending on the type of environment and the biology of the plants and animals affected. The more naturally variable the environment, the less effect dredging and disposal will have. Animals and plants common to such areas are adapted to unstable sediment conditions and thus have life cycles which allow them to better withstand the stresses imposed by dredging and disposal. Lateral migration of organisms and larval recruitment seem to play an important role in recolonization. Disturbed sites may be recolonized by opportunistic species which are not normally the dominant species occurring at nearby undisturbed sites.

Many species of motile, sediment-dwelling animals are able to move vertically through dredged material. The physical characteristics of the sediment overburden are very important in the process of vertical migration. Laboratory tests showed that when dredged material was physically similar to that in which animals normally occurred, there was little problem in vertical migration. However, placement of mud on a sandy bottom or vice versa can be detrimental.

## Sediment Suspensions

Most organisms are not seriously affected by the suspended sediment conditions created in the water column by dredging and disposal operations. Coral reef communities may be exceptions to this generalization, and deposition of suspended sediment can smother some fish eggs. Generally, however, only concentrations of suspended sediments well

above those created during most dredging and disposal operations cause mortality. Organisms normally associated with mud environments are highly tolerant of sediment suspensions; organisms not closely associated with muddy habitats are somewhat more sensitive. Suspended sediment tolerance generally decreases with increasing temperature or decreasing dissolved oxygen. In some cases studied, dredging-induced turbidity may have effects on local community function, such as photosynthesis, but these effects are transitory. There is probably no significant impact of suspensions of uncontaminated or lightly contaminated sediments. Contaminated sediments increase the potential for adverse impact on organisms. While water column turbidity created by dredging or disposal is probably not of major environmental concern, it may be a very real aesthetic problem.

The most serious form of turbidity is the condition known as fluid mud or fluff. Fluid muds present an extreme stress to bottom environments, as they are usually low in dissolved oxygen and will not physically support the upward movement of covered organisms to relatively clear overlying water. Fluid muds can have particularly deleterious effects where they form a blanket over fish spawning grounds and bottom areas critical in the juvenile life stages of aquatic organisms. At suspended sediment concentrations typical of fluid muds, the direct impacts on adult macrofauna may be significant, particularly if the muds are chemically contaminated.

Sediment suspensions associated with dredging and disposal are unavoidable. Mitigating measures should be considered where there are reasonable indications that aesthetically or environmentally objectionable sediment suspensions are likely to result. These measures are best applied to each dredging and disposal operation by considering the general characteristics of the local environment during the development of the work plans. Operational practices which minimize turbidity at the expense of increasing the thickness of fluid mud layers, or vice versa, are existing alternatives.

Measures to minimize water-column turbidity should especially be taken where dredging is done in natural systems that require clear water,

such as coral reefs and aquatic plant beds. Data suggest that in certain instances dredging and disposal schedules should be made to coincide with seasons in which local biota are at a low ebb in their productivity or reproductive cycle.

All of the above factors should be evaluated in selecting a disposal site, method and season to minimize the habitat disruption of disposal operations. Available data strongly indicate that physical habitat disruptions due to disposal are minimized at sites which have a naturally unstable or shifting substrate due to wave or current action. Habitat disruption can also be minimized by matching the physical characteristics of the dredged material to the substrate found at the disposal site. An understanding of the biological community that exists at the disposal site can further aid in minimizing habitat disruption. Recovery from physical impacts will generally be most rapid if disposal operations are completed shortly before the seasonal peak in spawning or larval abundance. Disposal sites should be located so as to avoid sensitive or critical habitats such as fish spawning or nursery grounds that are used on a seasonal basis.

Management of disposal operations should take into consideration both the physical and chemical impacts potentially associated with the dredged material. Evaluations must be made on a site-specific, case-by-case basis for each proposed disposal operation.

## Indirect Effects of Sediment Contaminants

Aquatic sediments act as natural depositories for contaminants such as heavy metals, persistant pesticides, polychlorinated biphenyls, and petroleum hydrocarbons. A number of conceptualized impacts center on the possibility that when the sediments are disturbed by dredging the sediment-associated contaminants might exert a toxic effect on aquatic organisms.

Investigations on the availability of sediment-sorbed heavy metals to organisms showed bioaccumulation of metals to be minimal and highly variable. For most metals studied uptake by organisms was not evident. Some researchers felt that relatively few isolated instances of heavy

metals accumulation from sediments could be interpreted as ecologically meaningful in terms of direct toxicity to the organisms and its predators, or as a pathway for the entrance of sediment-sorbed heavy metals into aquatic food chains. The variable accumulation and release of heavy metals demonstrated by test organisms have not been directly correlated with dredging and disposal operation or with the total amount of heavy metals present in the sediment. The potential for bioaccumulation of a metal associated with sediments appears to depend on the physical and chemical forms of the metal and varies from one sediment and organism to the next.

Development of a chemical extraction method for sediments which would reflect the availability of heavy metals to organisms has been pursued. Studies to date have not produced such a technique. There is little or no correlation between the levels of heavy metals taken up by organisms and the concentration of heavy metals in the sediments. Thus, there is no simple chemical method for environmental impact evaluation of metals in dredged material prior to its disposal. Bulk analysis of sediments for metal content cannot be used as a reliable index of metal availability and potential ecological impact of dredged material. Immediate release of soluble, and thus potentially biologically active, components from the sediment may be predicted by the elutriate test. Even so, presence of a contaminant in the standard elutriate predicts only the potential for, not the actual occurrence of, organism uptake or ecological impact. Obviously, absence of a particular contaminant would remove it from consideration.

Laboratory studies indicated that selected estuarine and freshwater organisms can be exposed to sediments that are contaminated with thousands of parts per million oil and grease with minor mortality for periods of up to 30 days. The uptake of hydrocarbons from even highly contaminated sediments is relatively minor.

Although oil and grease levels could be high in sediments, a large part of what is routinely reported as "oil and grease" may be harmless elemental sulfur. A large part of the hydrocarbon burden of sediments

is not eluted from sedimentary particles, nor is it available for gross uptake into the aquatic organisms tested.

Bioaccumulation by itself is difficult to interpret in terms of toxicity. Accumulation of a known toxicant in a human food source is of obvious importance. Accumulation by an organism may or may not affect the ecosystem. Accumulation may indirectly affect the organism through increased energy requirements for detoxification, lowered fecundity or abnormal larval development. Resultant effects on species abundance and population dynamics within localized systems can culminate in unexplainable population decline over a long period of time. Bioaccumulation of a contaminant can be followed by depuration and a return to baseline levels that existed prior to dredging and disposal.

Available research, although not covering all eventualities, shows that dredged material is not as toxic to aquatic organisms as originally conceived. Toxicants are not readily desorbed from sediment attachment and are thus less toxic than in the free state, on which most toxicity data are based. There are now cogent reasons for rejecting many of the conceptualized impacts of disposed dredged material regarding potential toxicity based on classical bulk analysis determinations. However, some sediments are toxic and uncontrolled disposal of these sediments may cause environmental harm.

Toxic properties of sediments can be due to the action of one or more pollutants acting singly or together (synergism) or to unidentified contaminants, particularly organic compounds. The diversity of variables strongly argues for the use of a whole-sediment bioassay to determine potential toxicity of dredged material for disposal, as now promulgated by the Environmental Protection Agency/Corps of Engineers. Although the specific procedures have yet to be fully evaluated under a wide range of environmental conditions, a period of evaluation and modification as necessary will probably validate the bioassay approach to regulatory testing. Such testing should uncover site-specific toxicity problems which can be addressed by appropriate chemical testing and biological evaluation of dredged material.

# PREFACE

This report synthesizes data from the U. S. Army Engineer Waterways Experiment Station (WES) Dredged Material Research Program (DMRP) Task 1D. The objective of Task 1D was to obtain knowledge concerning the environmental impacts of dredging and disposal on aquatic organisms. In addition to contracted work units of DMRP Task 1D, several other task areas of the DMRP provided valuable cross-correlated information. Data from several recently completed local studies helped in verifying and broadening the interpretation of the DMRP studies, for example, certain work units within the Dredge Disposal Study, contracted and managed by the U. S. Army Engineer District, San Francisco. Selected references from the open literature have been included where appropriate.

Most of the work on this report was carried out by personnel of the Marine Sciences Division, Naval Biosciences Laboratory (NBL) of the University of California, Berkeley. The contributions of Dr. R. Peddicord warrant the inclusion of his name as an author. The Principal Investigator and Director of the Naval Biosciences Laboratory was Dr. Neylan A. Vedros.

Special thanks are extended to Dr. Steven Obrebski (University of the Pacific, Pacific Marine Station) for his statistical evaluations of selected data. Dr. H. Wolochow (NBL) provided editorial comments. Ms. Phyllis Butterworth and Ms. Caro Hopper (NBL) typed the final reports.

Contract Manager for WES was Dr. Peddicord. The study was under the supervision of Dr. Robert M. Engler, Environmental Impacts and Criteria Development Project Manager, and under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory.

Commander and Director of WES during the preparation of this report was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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# EFFECTS OF DREDGING AND DISPOSAL ON AQUATIC ORGANISMS

## PART I: INTRODUCTION

1. This report synthesizes research carried out under Task 1D of the U. S. Army Engineer Waterways Experiment Station (WES) Dredged Material Research Program (DMRP). The objective of Task 1D was to determine direct and indirect effects of dredging and disposal on aquatic organisms. Dredging and disposal are carried out in different locations throughout the United States and in the territorial sea. Very often disposal is carried out in an environment different from the dredging site. Dredging and disposal occur in waters ranging from fresh to estuarine and high salinity waters. Some of these waters are highly turbid, whereas others normally are quite clear. Different dredging areas may have different contaminant burdens in waters and sediments. Another major variable is the organisms present and the species diversity in different dredging and disposal areas. Some benthic substrates may host hundreds of species within areas of a few square metres while other substrates may host very few species. The presence of many different species at a given location has been classically interpreted as the sign of a healthy ecosystem. This is not always true, and it is important to also take into account the number of major different types of organisms. For example, in the Oakland Inner Harbor of San Francisco Bay, there is great animal diversity, but most of the different species are sludge worms, with a number of other species which are diminutive, opportunistic, and adapted to pollutant stress. Conversely, potentially damaged species may be of commercial value, i.e., the east coast oyster beds. Local pollutant additions unrelated to dredging may exceed potential dredging and disposal effects or may act synergistically with dredging and disposal to produce deleterious or beneficial environmental effects. Even different methods of dredging and disposal may affect the environmental impact of any given project.

2. Previous literature on dredging and disposal has been fragmentary and site or resource specific. Reviews of literature reveal that too few

basic data exist in most studies to make general conclusions on the effects of dredging and disposal on aquatic organisms. However, these early data form a broad scale conceptual framework for the possible environmental impacts.

3. It is of the utmost importance to recognize that criticisms of dredging and disposal in the past were often based on conceptualized, rather than experimentally determined, environmental impacts. The fact that hypotheses exist or are under test does not prove the existence of real environmental impacts as erroneously assumed or implied by many persons and organizations. Many of the impacts documented in the past were due to practices which have been modified or eliminated in the wake of recent environmental enlightenment.

4. The comprehensive, in-depth examination of research needs carried out by Boyd et al.[1] provided a fundamental basis whereby general characteristics of disposal could be identified and research begun. It was recognized in the early stages of the DMRP that problems of organism impact, other than those directly measurable at the time of dredging or disposal, would require extensive research. Table 1 lists environmental impacts potentially associated with dredging and disposal which may also exert impacts on organisms. Task 1D was structured primarily to address these potential impacts. Field and laboratory studies were carried out on several different topics in order to develop generally applicable information, using organisms or organism systems which would provide initial estimates of the potential impacts conceptualized in Table 1.

## Task 1D Studies

5. The following paragraphs summarize the various work units of DMRP Task 1D.

### Physical impacts

6. Work Unit 1D10[3] determined response patterns of communities of bottom-living organisms following dredging and the disposal of dredged material in Monterey Bay, California. This study, as well as demonstrating local effects, provides a model of succession which may be

Table 1

Potential Direct or Indirect Environmental Effects of Dredging and Disposal of Dredged Material on Aquatic Organisms

| Potential Effects | Type of Influence | Reference No. |
|---|---|---|
| Physical disruption of the bottom | Removal or burial of organisms or communities, alteration of habitat | 2,3,4 |
| Bottom topography effects | Changed water flow regimes, alteration of local salinities, changed sedimentation patterns | 5,6,7 |
| Suspension of sediments | Lethal or sublethal effects due to smothering or physiological stress, aesthetic impacts | 4,8,9,10,11 |
| Alteration of water quality | Direct effects on dissolved oxygen, nutrient and ammonia content of water | 10,12,13,14, 15,16,17 |
| Release of sediment-bound toxicants | Direct or indirect toxicity to organisms, bioaccumulation of toxicants through food web | 10,11,12,13, 14,15,16,17, 18,19,20,21, 22,23,24 |

applicable in many dredging and disposal situations. This study was concerned with the gross physical impacts, measuring succession and recolonization following an environmental disturbance.

7. In Work Unit 1D03, Maurer et al.[2] reported on the abilities of motile bottom-dwelling organisms to migrate vertically through an overburden of dredged material. Laboratory tests utilized a number of representative species buried under different thicknesses of dredged material. The animals' preferred substrate, as well as sediment types with which the animals were not familiar, were used in the tests.

8. The gross physical impact of dredged material disposal is also the concern of Work Unit 1D12,[4] carried out in field research in the James River, Virginia. This work provides an initial estimate of the impact on organisms of fluid mud which can be caused by some dredged material disposal operations.

9. Bridging the gap between physical and chemical effects is Work Unit 1D09,[11] concerning effects of suspended sediments on representative organisms under laboratory conditions. In these studies, organisms were exposed to varying amounts of different sediments in suspension to determine levels causing lethal or other discernible effects on selected aquatic species. The test organisms were also analyzed for bioaccumulation of a variety of contaminants.

Chemical impacts

10. The potential availability and uptake of sediment-associated heavy metals by deposit-feeding benthic animals was the subject of Work Unit 1D06.[19] This laboratory study attempted to determine the biological availability of selected heavy metals associated with sediments and the potential for their uptake from dredged material into the tissues of representative bottom-dwelling species.

11. Sediment chemistry in relation to organisms impact was further studied in Work Unit 1D11.[21] This study carried out laboratory experiments on the transfer of oil and grease residues from oil-contaminated sediments into the tissues of some representative benthic species.

## Direct and Indirect Effects

12. Direct effects of dredging on organisms may occur in the path of the dredge, particularly in new work areas, or in previously dredged areas which have become recolonized by bottom organisms. Direct effects also result from disposal operations. In areas such as known oyster or clam beds, fishing grounds, etc., the biological communities which might be disrupted are relatively well known. In other cases, so little may be known about local biological resources that if any impact occurred, it would be difficult or impossible to measure due to the absence of baseline data. Baseline biological data are of greatest value when they include studies on seasonal, annual, or other cyclical variations in populations of benthic organisms at the site.

13. Indirect effects on organisms include those effects which are not immediately measurable as a consequence of dredging or disposal operations. Such effects may conceptually be manifested over extended periods of time and/or at some distance away from the dredging or disposal sites. The differentiation between direct and indirect effects is not always clear. Table 1 has not been subdivided into direct and indirect effects because of subjective difficulties in doing so. Parts II and III of this report deal primarily with direct effects of dredging and disposal, while Part IV deals primarily with indirect effects.

## PART II: PHYSICAL DISRUPTION OF BOTTOM ENVIRONMENT

### Review of Research

#### Habitat alteration

14. That dredging disrupts the benthic habitat at the excavation site is obvious. The substrate at the dredging site is removed and deposited within hoppers or barges or is pumped to a disposal site. Survival of organisms subjected to such mechanical stress is broadly variable. The long-term environmental concern is the repopulation of bottom areas where dredging or disposal has occurred. In dredging areas natural or established bottom communities are taken away, leaving a new substrate for colonization which may or may not resemble the original bottom sediments. In disposal, established bottom communities at the site will be blanketed with dredged material which may or may not resemble bottom sediments at the disposal site. Thus there is a need for information on both benthic recovery and recolonization, and on the vertical migration abilities of benthic organisms in newly deposited sediments.

15. The small amount of literature on this topic was reviewed by Anderlini et al.[22] Available information is based on site- and project-specific studies with no generally applicable principles derived. If any theme can be derived from the literature, it is that organisms in dredging areas are decimated, but populations recover in periods of a few months. Disposal of dredged material was of potential long-term significance, particularly in low-energy areas where disposal mounds persisted.

16. DMRP Work Unit 1D10 was a 4-year field study to evaluate spatial and temporal variations in benthic communities affected by dredging and disposal.[3] Controlled dredging and disposal were carried out at harbor, inshore, and offshore sites in Monterey Bay, California. An attempt was made to determine causal factors for species patchiness and successional variability within subregions of the same general type of environment. The study showed that organisms recolonizing dredged

material were not the same as those which had originally occupied the site and consisted of opportunistic species whose environmental requirements were flexible enough to allow them to occupy the disturbed areas. Trends toward reestablishment of the original community were noted within several months of disturbance, and complete recovery was approached within 1 year. There was no predictable sequence of recolonization of disturbed areas; however, vertical migration of existing organisms through the dredged material appeared not to be a factor in the recolonization. The study did not indicate the qualitative differences between existing bottom sediments and the deposited sediments in regard to organism impact. Disturbed areas such as shallower inshore waters, benthic regions near the head of a submarine canyon, and a harbor area were quicker to recolonize than normally undisturbed quiet water areas. The general recolonization pattern was dependent in major part upon the nature of the adjacent undisturbed community, which was able to provide a pool of replacement organisms capable of recolonizing the site by adult migration or larval recolonization.

Vertical migration

17. Most species of organisms normally found on sandy or muddy bottoms are more or less mobile, especially as juveniles. Few mud or sand dwellers are sessile (fixed to the bottom). The mobile organisms have various capabilities for moving through newly deposited sediments, such as dredged material, to reoccupy positions relative to the sediment-water interface similar to those maintained prior to burial by the disposal activity. Work Unit 1D03[2] revealed that benthic organisms such as mud crabs and amphipods having morphological and physiological adaptations for crawling through sediments were able to migrate vertically through deposits of tens of centimetres. Vertical migration ability was greatest in dredged material similar to that in which the animals normally occurred and was minimal in sediments of dissimilar particle-size distribution. However, results also showed broad variability in migratory abilities, suggesting physiological status and environmental variables to be of great importance to vertical migration ability. For example, in tests 2 years apart, the hard clam Mercenaria mercenaria showed

different results, which demonstrated intraspecies variability in escape response. Physiological condition and size of the organisms were probably contributing causes of the variability, as well as uncontrolled environmental variables. Mortalities of organisms were greater with greater time of exposure, and decreased temperature was correlated with decreased mobility through the sediments.

18. Maurer et al.[2] speculated that vertical migration of resident organisms after burial by dredged material should play an important role in recolonization of aquatic disposal sites. In their study, the majority of animals were able to migrate vertically through 32 cm of dredged material. This approximates the deepest overburdens seen in the field by Oliver et al.[3] However, the species present in early successional stages of recovery were not the same as those buried by the dredged material. Unfortunately, there are no field data directly comparable to the laboratory study by Maurer et al.[2]

19. A literature review[2] based on laboratory and limited field studies of other workers showed the following points:

- a. Disinterment ability of organisms appears to be related to life habitat and body or shell morphology. Most authors felt that organisms of similar life style and morphology would react similarly when covered with an overburden. For example, all epifaunal (surface-dwelling) forms are generally killed if trapped under dredged material overburdens, while infauna (subsurface dwellers) migrated to varying degrees. This factor can very likely be extrapolated across species lines.

- b. Exotic sediments (those in or on which the species in question does not normally live) are likely to have more severe effects when organisms are buried than sediments similar to those of the disposal site. Generally, physical impacts are minimized when sand is placed on a sandy bottom and are maximized when mud is deposited over a sand bottom.

- c. Smaller animals of a given type of organism are generally more susceptible to the effects of burial than are larger organisms.

- d. There have been few attempts to determine the contribution of vertical migration to recovery after dredged material deposition.

20. Some of the above literature points deviated from the laboratory results by Maurer et al.[2] Such disagreement does not necessarily imply errors in the literature, nor in recent research results, but rather argues for the need for specific case-by-case evaluation of potential problems.

21. Maurer et al.[2] recognized that the physical characteristics of dredged material were not alone in controlling vertical migration of buried organisms. They postulated that ammonia toxicity and oxygen deficiency in interstitial sedimentary waters could affect the physiology and behavior of buried organisms and thereby stimulate the vertical migration response.

## Conclusions and Interpretations

22. Dredging and disposal operations have immediate localized effects on the bottom life. The recovery of the affected sites occurs over periods of weeks, months, or years, depending on the type of environment and the biology of the animals and plants affected. The more naturally variable the environment, the less effect dredging and disposal will have, because animals and plants common to the unstable areas are adapted to stressful conditions and have life cycles which allow them to withstand the stresses imposed by dredging and disposal.

23. Many species of motile, sediment-dwelling animals are able to crawl vertically through certain layers of dredged material. Laboratory studies suggest this may very well occur at disposal sites, although field evidence is not available. Literature review suggests the vertical migration phenomenon to be highly variable among species.

## Applications and Regulation

24. The available literature shows that habitat disruptions due to disposal are minimized at disposal sites which have a naturally unstable or shifting substrate due to wave or current action. At such sites the dredged material is rather quickly dispersed, instead of covering the

area to substantial depths. This natural dispersion, which usually occurs most rapidly and effectively during the stormy winter season, can be assisted by conducting the disposal operation so as to maximize the spread of dredged material, producing the thinnest possible layer of overburden. A general case in point is ocean disposal in offshore deepwater areas. Such disposal operations deposit dredged material in quiet bottom areas not subject to turbulent water movement, resulting in bottom coverage by dredged material which can be expected to remain in place for long periods of time. The thinner the layer of overburden, the easier it is for motile organisms to survive burial by vertical migration through dredged material. When disposed sediments are dissimilar to bottom sediments at the sites, recolonization of the dredged material will probably be slow and carried out by organisms whose life habits are adapted to the new sediment. The new community may be different from that originally occurring at the site.

25. The desirability of minimizing physical impacts by dispersion can be overridden by other considerations, however. For example, dredged material shown by biological or chemical testing to have a potential for adverse environmental impacts might best be placed in an area of retention, rather than dispersion. This would maximize habitat disruption in a restricted area, but would confine potentially more important chemical impacts to that same small area. Additional information relative to chemical evaluation of dredged material may be found in the synthesis report on Task 1C.[16] Selection of sites and procedures designed to maximize dispersion or retention of dredged material are contained in the synthesis report on Task 1B.[5]

26. Habitat disruption can be further minimized by matching the physical characteristics of the dredged material to the substrate found at the disposal site. The ability of fauna to migrate is heavily dependent on the physical nature of the dredged material overburden.[2] Not only do overburdens of mud placed on sand produce maximum immediate impact, they change the nature of the substrate at the disposal site, often making it unsuitable for the species originally found there. Thus, a

new and different biological community may well develop at the disposal site.

27. Since larval recruitment and lateral migration of adults are primary mechanisms of recolonization, recovery from physical impacts will generally be most rapid if disposal operations are completed shortly before the seasonal increase in biological activity or larval abundance in the area. Both this consideration and the desire to maximize dispersion by wave and current action would argue in many cases for winter or spring scheduling of dredging and disposal operations.

28. Habitat disruption can also be minimized by locating disposal sites in the least sensitive or critical habitats. This can often be done on a seasonal basis. Known fish spawning or nursery grounds should be avoided just before and during use, but might be acceptable for disposal during other periods of the year. However, care must be taken to ensure that the physical substrate and biological community in spawning or nursery areas return to their original condition before the next use of the areas by the fish. Clam or oyster beds, municipal or industrial water intakes, highly productive backwater areas, etc., should be avoided in selecting disposal sites.

29. All the above factors should be evaluated in selecting a disposal site, method, and season to minimize the habitat disruption of disposal operations. All require evaluations on an individual basis by persons familiar with the ecological principles involved, as well as the characteristics of the proposed disposal operations and the local environment. Thus, evaluations must be made on a site-specific, case-by-case basis for each proposed disposal operation.

## PART III: SEDIMENT SUSPENSIONS

### Review of Research

#### Fluid muds

30. Open-water disposal of hydraulically dredged fine-grained dredged material with high water content can create fluid mud. Very little background information is available concerning the occurrence and effects of fluid muds. There is no generally accepted definition of fluid mud; Nichols, Thompson, and Faas[6] arbitrarily assign concentrations of greater than 10 g/ℓ suspended sediment to the fluid mud category. The impact of this phenomenon has been researched in DMRP Work Unit 1D12 by Diaz and Boesch,[4] who measured species diversity and populations in a predredging and postdisposal survey at a number of stations in the James River, Virginia. After dredging and disposal of the material in the river, several stations were found to be covered with up to 1.6 m of fluid muds. Different species varied in their responses to the environmental perturbation caused by the fluid mud. Insect larvae were most sensitive, being extensively lost from the environment. The more resilient species, particularly the oligochaetes, were only slightly affected. Recolonization of the substrate provided by the consolidating fluid mud took only 3 months due to the general resilience of the indigenous species and the naturally unstable physical conditions of the ecosystem studied. This recovery was monitored in late summer and early fall months. Recolonization, reproduction, and growth probably vary throughout the year, and the results obtained cannot be accepted as universal for the system unless studies are carried out during different seasons.

#### Turbidity

31. Habitat disruption or burial of organisms can be considered local in effect. Short of burial in compacted or fluid sediments, living organisms are exposed to varying levels of turbidity in water induced by dredging and disposal. The term turbidity properly refers to optical properties of water having to do with light adsorption and scatter, but

turbidity is commonly attributed to suspended sediments alone. It is used in this sense to refer to a broad spectrum of conditions, varying from what can essentially be considered a highly fluid mud, having several grams of particulates per litre, to particle suspensions of a few milligrams per litre, which appear clear to the eye.

32. Most ecosystems experience varying natural ranges of turbidity, to which resident fauna and flora are adapted. Conceptualized impacts of excessive turbidity include interference with filter-feeding activities of invertebrates, irritation and clogging of the gills in fishes, and interference with plant photosynthesis due to shading effects. The effects of turbidity and suspended sediments on the aquatic environment are the subjects of Work Unit 1D01.[8] This literature review points out that while water-column turbidity created by dredging or disposal is seldom an ecological problem, it is often a very real aesthetic problem.

33. Peddicord et al.[9] investigated the effects of graded suspensions of bentonite clay on several sensitive species of fish and invertebrate organisms in the laboratory. The material chosen was a potential irritant due to small particle size and jagged particle surfaces and also was similar in mineralogy and particle size to naturally occurring San Francisco Bay sediments. Research was designed to determine lethal concentrations of sediments for test organisms for periods up to 240 hr. In addition to varying concentrations of suspended solids, tests were carried out at temperatures of $10^{\circ}$ and $18^{\circ}C$ and under conditions of reduced dissolved oxygen. Results showed that mussels, shrimp, a polychaete species, an amphipod species, shiner perch, striped bass, and an isopod species were tolerant of suspended sediment loads much in excess of the few hundred milligrams per litre generally expected[17] in the water column during major dredging operations in San Francisco Bay. Organisms normally associated with mud environments were more highly tolerant of sediment loading in the water than organisms not closely associated with muddy habitats. Suspended sediment tolerance generally decreases with increasing temperature or decreasing dissolved oxygen, and the combination of summer temperature and low dissolved oxygen is particularly adverse.

34. Studies in DMRP Work Unit 1D09[11] used harbor sediments chosen for physical similarity to bentonite, in order to assay for impacts due to chemical properties of the sediments in suspension. Measurements were carried out using sediments from relatively uncontaminated reaches of San Francisco Bay and compared with measurements on more highly contaminated Bay sediments. Organism responses did not differ greatly between pure mineral suspensions and uncontaminated natural sediments. In many cases, lethal effects were more marked with the contaminated sediments. The most sensitive species tested, striped bass, *Morone saxatilis*, survived only a few hours at levels of 0.5 g/ℓ of contaminated sediments, a condition probably representing a worst case of turbidity generation associated with a dredging operation. Such conditions are very unlikely to occur in the field, where motile organisms may escape turbidity maxima, and where water currents disperse sediments as they settle out of the water column.

35. Chemical analyses of several species for heavy metals, pesticides and polychlorinated biphenyls (PCB's) indicated uptake of several contaminants, but none were accumulated to levels which appeared to be sufficient to influence the survival of the exposed organisms.[11] Difficulties in interpreting such chemical data argued for developing assays which evaluate total toxicity of a sediment regardless of specific toxicants. Various concentrations of contaminated sediment suspensions from the Duwamish Waterway in Seattle, Washington, were used by LeGore and DesVoigne[25] in 96-hr static bioassays. They were unable to demonstrate lethal or sublethal toxic effects in threespine sticklebacks and coho salmon fry.

36. Studies on physical impact of sediment suspensions suggest, in summary, that there is probably no significant impact of uncontaminated or lightly contaminated suspended particulate matter on a broad variety of organisms. When exposed to suspended sediment levels of several grams per litre for periods of days, the impacts may be significant, particularly if the muds are chemically contaminated (see Prater and Anderson[26] and Part IV of this report).

37. Studies of mortality do not completely determine the potential biological impact of suspended particulate matter on organisms. Studies by Sherk, O'Connor and Neumann[27] have shown numerous sublethal alterations in tissue morphology and physiology of test species exposed to suspensions of particulate matter representative of levels of turbidity potentially induced by dredging and disposal. The changes recorded were natural reactions to turbidity stress and it is not known to what extent they influence the fitness of the organisms tested. Indeed, such reactions are probably naturally evolved physiological defense mechanisms to natural turbidity stress. Peddicord and McFarland[11] noted mortalities and deformities in commercial crabs (Cancer magister) after several days in 9 g/ℓ of contaminated harbor sediments. Mortality occurred only when the crabs underwent molting. Such laboratory results, although of interest in the general field of environmental research, might be predicted to occur as a result of dredging and disposal only when fluid mud made possible the exposure times and concentrations necessary to cause such effects.

## Conclusions and Interpretations

38. Research results show that only concentrations of suspended sediment on the order of grams per litre maintained for days cause mortality in test animals and that contamination of the sediments increases the possibility of damage to organisms. The literature shows that in some cases dredging-induced turbidity may have effects on local community functions such as photosynthesis, but that these effects are transitory.[28] Coralline reefs might be permanently impacted by temporary high suspended sediment concentrations.

39. More serious than normal turbidity is the extreme sediment suspension near the bottom known as fluid mud or flocculent layer formation. Fluid muds present an extreme stress to bottom environments, as they are usually low in dissolved oxygen and persist for weeks or more before they are sufficiently consolidated to provide a solid foothold for bottom organisms. Fluid muds can have direct deleterious effects

on adult macrofauna, as well as indirect effects where they form a blanket over fish spawning grounds and bottom areas critical in the juvenile life stages of aquatic organisms.

## Applications and Regulation

40. Sediment suspensions associated with dredging and disposal are unavoidable. Mitigating measures should be employed where there are reasonable indications that aesthetically or environmentally objectionable sediment suspensions are likely to result. These measures are best applied to each dredging and disposal operation by considering the general characteristics of the local environment during the development of the work plans. The synthesis report on Task 6C[7] discusses alternative operational practices which minimize turbidity at the expense of increasing the thickness of fluid mud layers which may be created, or vice versa. That is, pipeline configurations which minimize water-column turbidity tend to produce fluid mud layers of maximum thickness and minimum areal coverage, while configurations producing maximum turbidity tend to produce fluid mud layers of minimum thickness and maximum areal extent.

41. The Task 1D work units showed that water-column turbidity is generally an aesthetic rather than an ecological problem and fluid mud has the potential for definite environmental impact. Therefore, in most cases the basic environmental question in selecting pipeline discharge configurations is whether fluid mud depth should be maximized over a small area, or minimized but cover a larger area. Although such a decision must be made locally after considering the unique characteristics of each case, indications are that a thick mound covering a relatively small area might be desirable in many cases. This would impact the smallest portion of the benthic habitat and organisms.

42. Measures to minimize water-column turbidity should especially be taken where dredging is required in clear water areas, in particular coral reefs, where dredging could potentially create enough turbidity to kill the local reef system. Peddicord et al.[9] suggested that, in certain instances, dredging and disposal schedules could be made to coincide

with seasons in which local organisms or biological communities were at a low ebb in their productivity or reproductive cycle.

## PART IV: INDIRECT EFFECTS OF SEDIMENT CONTAMINANTS

### Review of Research

43. There has been concern that contaminants from municipal, industrial, and other sources which become entrapped in aquatic sediments may become biologically active when disturbed by dredging or disposal activities. Major materials in question have been numerous heavy metals, persistent pesticides such as DDT and its derivatives, PCB's and petroleum hydrocarbons. Dredging and disposal do not introduce new contaminants to the aquatic environment, but at worst simply redistribute the sediments which are the natural depository of contaminants introduced from other sources.

#### Heavy metals

44. In Work Unit 1D06,[19] metal availability and accumulation studies were conducted using the clam *Rangia cuneata*, the grass shrimps *Palaemonetes pugio* and *P. kadiakensis*, and the worms *Neanthes arenaceodentata* and *Tubifex* sp. Test sediments were taken from Texas City and Corpus Christi, Texas, ship channels (15 and 30 $^{o}/oo$ salinity, respectively) and the Ashtabula River in Ohio (fresh water). Metals routinely measured were iron, manganese, copper, cadmium, nickel, lead, zinc, chromium and mercury.

45. For most metals studied, uptake by organisms was not evident. However, when uptake was shown to occur, the levels often varied from one sample period to another and were quantitatively marginal, usually being less than one order of magnitude greater than levels in the control organisms even after 1 month of exposure. It is invalid to compare metals levels in organisms to total sediment concentration since only a variable amount of the sediment-associated metal is biologically available. This is discussed in detail in the synthesis report on Task 1E.[29] In addition to not knowing the amount of metal available for biological uptake, animals in undisturbed environments may naturally have high and fluctuating metal levels. Therefore, comparisons should be made between control and experimental organisms at the same point in

time in order to evaluate bioaccumulation.

46. Of a total of 168 animal-sediment-salinity combinations evaluated in tests carried out by Neff, Foster and Slowey,[19] only 22 percent showed significant accumulation due to sediment exposure. The largest uptake was of iron, a metal generally known for its low degree of toxicity in biological systems. Significant accumulations of lead were seen in a number of short-term exposures, although these could not be duplicated in long-term exposures. Relatively high uptake of lead occurred only in the polychaete *Neanthes* and was interpreted to be potentially ecologically significant for this species. Their literature search showed that heavy metals in solution vary over several orders of magnitude in availability to benthic invertebrates. Although accumulation of heavy metals by organisms from the water has been documented, the literature shows no such clear evidence for accumulation of metals from the sediments.

47. Neff, Foster and Slowey[19] also investigated the depuration of heavy metals after the organisms were removed from the test sediments. In those 37 cases where there was uptake after 8 days exposure, depuration during 2 or 8 days in clean water was seen in 7 instances, with the other 30 cases showing no decrease in metal concentration in the tissues.

48. In a field investigation of the San Francisco Bay system, Anderlini et al.[22] looked at nine heavy metals (silver, arsenic, cadmium, copper, mercury, nickel, lead, selenium, and zinc) and five invertebrates (*Ampelisca milleri*, *Macoma balthica*, *Neanthes succinea*, *Mytilus edulis*, and *Ischadium demissum*). Metals concentration in sediments and organisms fluctuated within and outside the dredged zone during the period of the study. Changes in the mean metal concentrations in sediments and all invertebrates during the study period were relatively small, considerably less than one order of magnitude. Mean metal concentrations in sediments and benthic invertebrates changed by less than a factor of 2, and changes in metal levels in *M. edulis* were no greater than a factor of 3. These changes could not be directly attributed to dredging activities. Metal concentrations were similar in *M. edulis* which were transplanted from clean water to stations within and outside the dredged zone. Mussels

transplanted to contaminated Bay stations appeared to accumulate copper, nickel, and zinc over controls kept in clean water coastal stations but to a lesser extent than native mussels. Desorption of metal species by mussels 27 days after being transferred from Bay to ocean stations occurred in the following order of decreasing depuration: zinc > mercury > copper > lead > nickel > cadmium > arsenic. Selenium was not depurated from mussel tissue in 27 days.

49. The accumulation potential of a metal may be affected by several factors such as duration of exposure, salinity, water hardness, exposure concentration, temperature, and the particular organism under study. The relative importance of these factors varies from metal to metal. Data of Neff, Foster and Slowey[19] on salinity effects are inconclusive, but there was a trend toward increased uptake at lower salinities. Anderlini et al.'s[22] 9-day laboratory study exposed _M. balthica_ to the chloride salts of various metals in the water column. These data support field observations in which _M. balthica_ showed the highest metal concentrations following dredging periods where heavy rains had resulted in a marked decrease in salinity.

50. The Neff, Foster and Slowey[19] study indicated that the chemical form of metals had important effects on their bioavailability. Elevated concentrations of heavy metals in tissues of benthic invertebrates were not always indicative of high levels of metals in the ambient medium or associated sediments. Although a few instances of uptake were seen to be of possible ecological significance, diversity of results among species, different metals, types of exposure, and salinity regimes strongly argued that bulk analysis of sediments for metal content could not be used as a reliable index of metal availability and potential ecological impact of dredged material.

51. Neff, Foster and Slowey[19] performed sequential and nonsequential chemical extractions on the sediments to evaluate the potential mobility of metals in different chemical forms. They also determined the total metal concentration in the sediment. For some species a correlation did exist and for others a correlation did not exist between any chemical or physical form studied and bioaccumulation

of the metal. These authors stated: "At present, it does not appear that a simple extraction scheme can be developed that might indicate availability of sediment sorbed metals by benthic organisms. Additional data, based upon a large number of different sediment types, may indicate, however, forms most likely to be accumulated by benthic organisms."

52. For some metals there appears to be good correlation between metal concentration in the sediment and in the associated infaunal and epifaunal macrobiota.[19] For other metals no such correlation exists. These correlations often vary with sediment type. The correlation, when it occurs, may be due to direct or indirect transfer of metals from sediment to biota or it may represent the presence of a common source of metals to both the sediment and biota. Anderlini et al.[22] concluded that if changes in metals in the water occurred as a result of dredging activities, the changes were either less than small natural fluctuations or were of short duration.

53. Both Neff, Foster and Slowey[19] (short-term laboratory studies and literature review) and Anderlini et al.[22] (longer term field work and back-up laboratory experiments) have found the same heavy metal phenomenon. The accumulation and release of certain heavy metals seems to vary with the metal, with the species, between sampling times, between sampling sites (dredged and not dredged), and within controls. These variable results have not been directly correlated with dredging operations or sediment loading.

54. A recent field study supporting the laboratory results of Neff, Foster and Slowey[19] has been carried out by Simms and Presley.[30] These authors concluded that molluscs, crustaceans, and bony fishes from dredged areas of San Antonio Bay were lower in almost every heavy metal than were organisms from other areas where dredging was minimal. Molluscs were observed to concentrate metals more than any other organisms studied, but the levels observed were much lower than those thought to be lethal or toxic. Except for a few large fish, metal concentrations did not correlate significantly with size or growth stage. Vigorous shell dredging in the Bay for 50 years apparently did not cause increases of heavy metals in the tissues of local biota.

Oil and grease

55. This term is used collectively in describing all components of sediments of natural and contaminant origin which are primarily fat soluble. The literature review contained in Work Unit 1D11[21] demonstrated a broad variety of possible oil and grease components in sediment, the recovery of which was dependent on the type of solvent and methodology used to extract these residues. Trace contaminants, such as the PCB's and chlorinated hydrocarbons (DDT and derivatives), often occur in the oil and grease. Large amounts of contaminant oil and grease find their way into the sediments of the Nation's waterways either by spillage or as chronic inputs in municipal and industrial effluents, particularly near urban areas with major waste outfalls. The literature suggested long-term retention of oil and grease residues in sediments with minor biodegradation occurring. Where oily residues of known toxicity became associated with sediments, these sediments retained toxic properties over periods of years affecting local biota. Spilled oils are known to readily become adsorbed to naturally occurring suspended particulates, and oily residues in municipal and industrial effluents are commonly found adsorbed to particles. These particulates are deposited in benthic sediments and are subject to resuspension during disposal.

56. Using the elutriate test DiSalvo et al.[21] showed some release into the water of soluble hydrocarbon residues from sediments known to contain 2000 to 6000 ppm total hydrocarbons. Hydrocarbon concentrations in the elutriate (100 to 400 ppb) were from 11 to 400 times higher than background, yet were well below acceptable effluent discharge standards.[31] The amount of oil released during the elutriate test is less than 0.01 percent of the sediment-associated hydrocarbons under worst-case conditions.

57. A test scheme was employed in which estuarine crabs (*Hemigrapsus oregonensis*), mussels (*Mytilus edulis*), and snails (*Acanthina spirata*) and the freshwater clam, *Corbicula* sp., were exposed to contaminated sediments in order to determine magnitudes of uptake of hydrocarbons which were included in sedimentary oil and grease burdens.

58. There was no overt mortality of test organisms that was

directly attributable to exposure to contaminated sediments. Experimental evidence suggested slight uptake of hydrocarbons by saltwater test organisms incubated in the presence of Duwamish River sediments which contained almost 500 ppm total hydrocarbons. Freshwater clams exposed for 30 days to Duwamish River sediments showed no well-defined uptake of hydrocarbons. Mussels and crabs exposed for 4 days to New York Harbor sediments containing 2000 ppm total hydrocarbons showed average uptakes above background of about 50 to 70 ppm (2.5 and 3.5 percent, respectively, of the sedimentary hydrocarbon concentration).

59. These results indicated that selected estuarine and freshwater organisms can be exposed to dredged material that is contaminated with thousands of parts per million oil and grease and experience minor mortality for periods up to 30 days. Uptake of hydrocarbons from the heavily contaminated sediments appears minor when compared to the hydrocarbon content of the test sediments and when compared to results describing exposure of uncontaminated organisms under field conditions where total hydrocarbon uptake ranged to several hundred parts per million.[32]

Further considerations

60. In Work Unit 1D07,[20] attempts were made to trace pathways of uptake of sediment-associated DDT into the tissues of estuarine deposit-feeding benthic infauna. The data obtained suggested the possibility of uptake of DDT under model laboratory conditions which may or may not be operative under field conditions. Fulk, Gruber and Wullschleger[23] have reviewed the literature on pesticides and PCB's in sediments. Algae, suspended solids, bottom sediments, and water contain various chlorinated hydrocarbons. The studies conducted on the adsorption and desorption of chlorinated hydrocarbons on solids have generally indicated that these materials are much more readily sorbed than desorbed. These workers analyzed the sediments from five locations for aldrin, dieldrin, endrin, lindane, 2,4-D esters, DDT analogs, toxaphene, and PCB's. PCB's, dieldrin, and the DDT analogs were the most prevalent. The desorption of the latter materials was studied. No release of DDT residues was observed. Some dieldrin release was observed in the parts per trillion

range. On the basis of these laboratory studies, it appears that release of these water-insoluble pesticides will not occur to an appreciable extent during disposal. In another study, Anderlini et al.[24] monitored release from sediments and uptake by organisms of PCB's and compounds of the DDT group during a disposal operation in San Francisco Bay. Some uptake of p,p'-DDE was observed but the levels of the other chlorinated hydrocarbons remained constant in *Mytilus edulis*.

61. Ammonia is one of the potentially toxic materials known to be released from anoxic sediments and is routinely found in evaluations of sediments using the elutriate test.[14] Anderlini et al.[24] found indications of minor increases of ammonia in the water near a disposal area and rapid returns to baseline levels. Similar temporary increases in ammonia at marine, estuarine, and freshwater disposal sites have been documented in several DMRP field studies, but concentrations and durations are usually well below levels causing concern.[33]

62. A number of potential water-quality problems may occur which have indirect impacts on organisms. Where waters are not well mixed, and sediments are subject to high inputs of natural or contaminant organic materials, disposal of sediments may cause a rapid temporary depletion of dissolved oxygen in localized waters and may add hydrogen sulfide to the water column. Lack of oxygen in the water can be a stress factor, and hydrogen sulfide is a toxic substance which is normally retained in or slowly released from benthic sediments. These problems are highly site specific and are treated in greater detail in the synthesis report on Task 1C.[16]

63. There is a complex array of factors that contribute to the overall toxicity of a sediment. Sediments will also vary from one geographic location to another. A site-specific bioassay of the water extract of a sediment should provide the best indication of a potential indirect environmental impact. For example, Hoss, Coston, and Schaaf[34] found reduced survival of fish larvae during 14-day exposure to seawater extracts of contaminated Charleston Harbor sediments. These workers concluded that effluent water from confined dockside disposal sites could have harmful effects on fish larvae in the field.

## Conclusions and Interpretations

64. Research results show that dredged material is not as toxic to aquatic organisms as originally conceived, based on bulk sediment analysis. Nevertheless, some sediments are toxic and disposal of these sediments may cause environmental harm.

65. Work Unit 1D06[19] evaluated the possibility of obtaining a chemical extraction method for sediments which would reflect the availability of heavy metals to organisms. Studies to date have not produced such a technique, and there is no chemical method for environmental impact evaluation of dredged material prior to its disposal. Work Unit 1D11[21] showed that although oil and grease levels could be high in sediments, a large part of what is routinely reported as oil and grease may be harmless elemental sulfur, and a large part of the hydrocarbon burden of sediments is not released from sedimentary particles nor is it available for gross uptake into the aquatic organisms tested.

66. Bioaccumulation by itself is difficult to interpret in terms of toxicity. Accumulation of a known toxicant in a human food source is of obvious importance. Components can be transferred through aquatic food chains with biomagnification. Accumulation may stress the organism and make it more susceptible to disease or predation. Necessary energy may have to be diverted into detoxification mechanisms. Lowered fecundity and abnormal larvai development will ultimately have effects on species abundance and population dynamics within localized systems. These kinds of sublethal effects can culminate in unexplainable population decline over an extended period of time.

## Applications and Regulation

67. The conceptual problem of toxicants associated with sediments must be evaluated in light of valid chemical and biological data describing the availability of toxicants to organisms and the water column prior to determining effects of such toxicants. Information must then be gained as to the effects of specific substances on organism survival and function.

Many materials previously regarded as toxicants are not readily desorbed or released from sediment attachment and are thus less toxic than in the free or soluble state, on which most toxicity data are based.

68. Prater and Anderson,[26] using a 96-hr bioassay technique with four different species of organisms, evaluated the toxicity of sediments from the Duluth, Minnesota-Superior, Wisconsin harbor. Sediments could be broadly classified on an arbitrarily selected scale as nonpolluted, moderately polluted, and heavily polluted using the bioassay. The results of an array of chemical analyses also led to an arbitrary designation of nonpolluted, moderately polluted, and heavily polluted sediments. In 75 percent of the cases chemical analyses supported bioassay results, but they were unable to identify the causal chemical factor for mortality. Concentrations of chemicals thought to be pollutants varied from one station to another and were not always highest at stations producing highest mortalities. Toxic properties of the sediments could have been due to the action of one or more pollutants acting together (synergism) or to unidentified contaminants, particularly organic compounds. This strongly argues for the use of a whole-sediment bioassay to determine potential toxicity of dredged material for disposal.[35] Although the suggested procedures have yet to be fully evaluated under a wide spectrum of environmental conditions, experience will undoubtedly validate this type of test over the long term.

69. There are now cogent reasons for rejecting many of the conceptualized impacts of disposed dredged material regarding potential toxicity based on classical bulk analysis determinations. It is invalid to use total sediment concentration to estimate contaminants levels in organisms since only a variable and undetermined amount of sediment-associated contaminants is biologically available. Although a few instances of uptake of possible ecological consequence have been seen, the fact that uptake depends on species, contaminants salinity, sediment type, etc., argues strongly that bulk analysis does not provide a reliable index of contaminant availability and potential ecological impact of dredged material.

## PART V: CONCLUSIONS

70. Based on the data synthesized in this report the following conclusions can be drawn:

- a. Determination of potential environmental effects of dredging and disposal is in preliminary stages due to the multiplicity of variables involved.
- b. Direct effects of dredging and disposal are fairly straightforward when carried out in locations where direct observations of effects can be made. Direct effects include decimation of organisms at dredging sites and burial of organisms at disposal sites. Direct effects are restricted to the immediate areas of dredging or disposal. Recolonization of sites occurs in periods of months in cases studied. Disturbed sites may be recolonized by opportunistic species which are not normally the dominant species occurring at the site.
- c. Most organisms tested are very resistant to the effects of sediment suspensions in the water, and aside from natural systems requiring clear water such as coral reefs and some aquatic plant beds, dredging-induced turbidity is not of major ecological concern. The formation of fluid muds due to dredging and disposal is a poorly understood process and is of probable environmental concern.
- d. Release of sediment-associated heavy metals and their uptake into organism tissues has been found to be the exception, rather than the rule. Results demonstrate there is little or no correlation between bulk analysis of sediments for heavy metals content and their environmental impact.
- e. Oil and grease residues, like heavy metals, appear tightly bound to sediment particles, and there appears to be minimal uptake of the residues into organism tissues. Of the thousands of chemicals constituting the oil and grease fraction, very few can be considered to be significant threats to aquatic life.
- f. Most studies reviewed in this report describe worst-case experimental conditions where relatively short-term exposures to high concentrations of sediments and contaminants were used. Although limited in scope, experimental results showing lack of effects under these conditions support the conclusion that indirect

(long-term and sublethal) effects of dredging and disposal will be minimal. The diversity of variables argues for an integrated, whole-sediment bioassay using sensitive test organisms as currently under development by the Corps of Engineers and the Environmental Protection Agency. Such testing should uncover site specific toxicity problems which can be addressed by appropriate chemical testing and biological evaluation of dredged material.

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Effects of dredging and disposal on aquatic organisms / [by Nina D. Hirsch, Louis H. DiSalvo, Richard Peddicord]. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

41 p. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; DS-78-5)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

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TA7.W34 no.DS-78-5